INTRODUCTION

In recent years, the amount of land being brought under irrigation has increased dramatically in the subhumid and semiarid regions of the United States and throughout the world. In Nebraska alone, between 0.10 and 0.13 million ha are being added annually to the almost 3.4 million ha already under irrigation. This expansion of irrigation has created a greatly enlarged agricultural demand for water. At the same time, industrial, municipal and recreational demands for water have also grown.

The need for expanded food production to feed a hungry world has provided impetus for much of the growth in irrigation and has made agricultural use of water more economically competitive. This swelling demand for water, coupled with increasing energy costs to move the water, makes it imperative to refine or change many present irrigation practices. Practices such as irrigating by the calendar or applying water too liberally result in the waste of water, energy and fertilizer. Not only is excessive irrigation wasteful of resources and money but it often results in reduced yields. Leaching may remove nutrients from the root zone, roots may be poorly aerated and conditions favorable to development and spread of plant disease may develop.

Were it possible to reduce water application by 1 mm per day on the irrigated land of Nebraska alone through proper irrigation practices, over $1,500,000 a day in pumping costs could be saved. The water conserved on this one day would supply the annual water needs for an additional 1900 ha of land or supply water to a city of 250,000 people for a year.

Skillful, efficient management of water in agriculture will require knowledge of crop moisture status. Crop temperature is an indicator of the degree of moisture stress that the crop experiences. Thus, for example, the temperature of a crop may indicate the first exhibition of minor water stress. Irrigation could then be scheduled to replenish the soil moisture supply before further stress develops. In other cases application of irrigation water may be necessarily limited in order to reduce the overall demand for water. This increases the probability of moisture stress developing during the growing season. Because stress beyond a certain level can result in drastically reduced yields, it is necessary to carefully monitor the crop water status and to allocate the available water in such a way as to alleviate stress conditions before this critical level is reached. Crop temperature data may provide useful guidance in scheduling such irrigations.

Crop temperature data have several uses beyond that of irrigation scheduling. For example, they may serve as input into recently developed models for estimating evapotranspiration over large areas. Reliable estimates of the degree and extent of moisture stress induced in crops and rangeland by drought, can be made with surface temperature measurements. These data would be useful to government agencies and others charged with responsibility for predicting crop yields or assessing the economic impact of reduced yields resulting from drought.

Various crops exhibit different temperature responses to water stress. Crop temperature responses of many major agricultural crops grown in the Great Plains are not well understood. Such

responses can be affected by the various kinds of weather that occur in the Great Plains region. For example, it has been shown that crops in the Great Plains are often subject to very high water demand because of the advection of large quantities of sensible heat into the region by hot, dry winds coming from other, more arid regions. Temperature response under these circumstances is probably different than under other kinds of weather regimes. An understanding of these differences is vital if such temperature data are to be used in the applications decribed above.

The research reported in the ensuing Chapters of this report was conducted to provide information pertaining to the temperature response of some of the major agronomic crops, especially corn and sorghum, which are commonly grown in the Great Plains region under both irrigated and dryland conditions. The prime objective of the research has been: to evaluate the use of remotely sensed crop temperature data as a tool in the management of water resources. The subsidiary objectives without which the primary objective could not be achieved were: (1) to determine the temperature response of major agronomic crops to varying climatic and moisture conditions; (2) to test methods based on crop temperature and/or other readily measureable meteorological parameters for their accuracy in estimating crop stress or heat stress conditions and (3) to determine the feasibility of using crop temperature data as a guide for irrigation scheduling.

These objectives have been achieved for a few agronomic crops. The bulk of the research was conducted on sorghum and corn at the University of Nebraska Sandhills Agricultural Laboratory located

near Tryon, Nebraska (41° 37' N; 100° 50' W and 975 m above mean sea level) in 1978 and 1979. Some of the research work was done in 1978 at the Mead Agricultural Laboratory (41° 09' N, 96° 30' W and 354 m above mean sea level).

This final report consists of 11 chapters and 4 appendices. Each chapter has been written in a form roughly appropriate for publication. Most of the chapters will, in fact, be submitted to scientific journals in the near future. In essence then, these chapters may be considered to be "preprints." Hence, the reader may find occasional redundancy between chapters, especially with regards to the literature review and material and methods sections.

Chapters I and II contain data which were from preliminary studies in addition to data taken during the 1978 and 1979 studies. Chapter I describes the temperature response of several different types of vegetation growing under similar moisture and climatic conditions. In this chapter the agreement between crop temperatures measured with attached leaf thermocouples and with infrared thermometers is described.

In Chapter II thermal imagery and IR thermometer data are examined to determine if the crop temperature variability across a field at different times during the day may be indicative of the degree of water stress occurring. Findings on the optimum time of day for detecting maximum moisture stress by plant temperature measurement are also reported. The correlation between seasonal evapotranspiration amounts and the seasonal plant temperature differences (between stressed and non-stressed crops) is presented in Chapter II.

Chapter III summarizes the results of the 1978 studies on corn, sorghum and soybeans at Mead. The use of crop temperature data to schedule irrigation for these crops is discussed. Differences in the temperature response of the three crops to similar irrigation treatments are reported.

In Chapter IV the effects of water stress on crop height, plant phenology and grain yield are discussed. The effects of various irrigation treatments during critical growth stages on the temperature response and the grain yields are examined. Five different crop temperature indices are tested for their ability to predict phenological growth stage.

Chapter V contains information on the leaf and air temperature patterns in corn subjected to differential irrigation treatments. Mid-day differences in canopy temperature between stressed and non-stressed plants are examined as is the standard deviation of temperature in irrigated and non-irrigated areas. The difference between mid-day leaf and air temperature and the relationship to the detection of plant stress is evaluated. The relationship between the severity of stress and the time of day when plant temperatures become elevated is also discussed.

The temperature response of 3 hybrids of sorghum under a range of water stress conditions is reported in Chapter VI. Relationships between crop temperature, grain yield and evapotranspiration rates are evaluated in this chapter.

The results of using crop temperatures measured with an IR thermometer to schedule irrigation in corn are presented in Chapter VII. Included in this chapter are data on the affects of scheduling irrigation from predetermined canopy temperature levels on

final grain yields.

Differences in the temperature developed in 9 hybrids of corn at various levels of water stress and differences in canopy temperatures as a function of plant populations are given in Chapter VIII.

In Chapter IX a number of environmental factors which may affect the measurement of canopy temperatures with an infrared thermometer are described. The factors include: cloudiness, windspeed, solar azimuth, solar elevation, level of soil nitrogen and the direction from which the field is viewed by the IR thermometer.

Chapter X contains a discussion of a stress index which was developed to indicate the severity of water stress. This index involves temperature difference between stressed and non-stressed vegetation as measured during mid-morning and mid-afternoon.

The final Chapter evaluates the feasibility of using multispectral data obtained from overflights by NASA aircraft as a means of assessing the moisture status of corn and, also, to detect hail damage.

We wish to express our sincere appreciation to Dr. Darrell Watts, Dr. Wayne Kroutil and Mr. William Kranz of the Agricultural Engineering Department UNL/IANR who designed and operated the irrigation systems at SAL. These individuals also provided valuable assistance in the management of the research plots and collected data which they have graciously made available to us. We also appreciate the cooperation of Dr. Charles Y. Sullivan of the Department of Agronomy who helped design experiments in some of the plots. We are grateful for the excellent cooperation of

several individuals at the North Platte Experiment Station -- especially Mr. Neil Baxter, Dr. Gary Hergert, Mr. Dennis Wilson and Mr. Ed Schwartz. Without their valuable assistance it would have been extremely difficult to accomplish our research objectives. We acknowledge the helpful comments and suggestions of Dr. Shashi B. Verma and Dr. John Norman. Mr. Jim Hines assisted us in our data computations and analysis. Mr. Dale Sandin and Mr. Tom Keber provided technical assistance in conduct of the experiments. Ms. Lee Donelson and Ms. Norma Gottschlak assisted in maintenance of the research plots and in several data collecting activities. Wayne Hall, Gary Lewis and Karen Stork of the Nebraska Water Resources Center offered helpful suggestions in developing the proposal and were very cooperative in making necessary changes in the conduct of the research and in preparation of the final report. Mrs. Roberta Sandhorst, Mrs. Nancy Brown and Mrs. Betty James have, with good humour, typed the many drafts of this report. Marty Shaneyfelt drew the majority of the figures appearing in this report.

The contents of this publication do not necessarily reflect the views and policies of the Office of Water Research and Technology, U.S. Department of the Interior, nor does mention of trade names or commercial products constitute their endorsement or recommendation for use by the U.S. Government.

This completion report was sponsored in part by the Nebraska Water Resources Center, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln.